Blue-Water EEMS - TDRSS

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SUMMARY

The Environmental Electromagnetic Modelling System (EEMS) package is being developed in two stages. EEMS VI .0. colloquially called Blue-Water EEMS. is intended to provide the Royal **Navy** with an interim capability prior to the introduction of the new Command Support System (CSS). Blue-Water EEMS is a direct replacement for **the existing** Integrated Refractive Effects Prediction System (IREPS) package and **does not** incorporate terrain handling in its calculations.

Blue-Water EEMS consists of the radar propagation model TERrain Parabolic Equation Model (TERPEM) and the Target Detection Range Software Suite (TDRSS). The TERPEM module will support the production **of the** path-loss coverage diagrams and will be the primary input into TDRSS. The TDRSS module will then calculate the radar performance and susceptibility to detection of a specific threat using the radar receiver and operator characteristics.

INTRODUCTION

TDRSS investigates the performance **of radar systems in detecting incoming targets and generates tactically useful information.** The targets are assumed to be approaching the radar directly in a straight path. flying towards or away from the radar antenna, The model predicts the detection ranges of airborne targets by airborne and shipborne surveillance radars in the prevailing refractivity regime,

The primary objectives when designing TDRSS were to construct representations of, and determine the effects of. the following aspects of the target detection and identification process:

- radar antenna rotation rate;
- target closing speed:
- radar system detection logic;
- radar operator performance;
- radar screen range settings,

INPUTS

Two prototype packages: PREdicted Detection Ranges of Airborne Targets in Operational Regimes (PREDATOR) and the Predator Radar Model (PRAM), both developed in-house by MWC (OAD), form the TDRSS module of EEMS. The following are inputs into TDRSS:

Radar type - A high level description of the radar system detailing the radar system transmission characteristics.

Environment - details electromagnetic propagation in specific environments. This information comes from the TERPEM model as a file containing a set of path-loss against range values for a target height profile in the prevailing refractivity environment.

Target height - is used to select the appropriate path-loss vs range table from the TERPEM output file. It will be expanded to provide a full height vs range profile of the target during its flight.

Target RCS - based on the RCS value given in m^2.

Target Closing Speed - is the actual closing speed between the radar platform and target.

System Performance (S_p) - defines the 'Blip-scan' relationship that characterises the valid contact criteria. Typically there will need to be a number of returns above a nominal detection threshold before the system will respond to a valid contact. In a number of warfare areas this is defined by the 5 out of 8 rule i.e. there must be 5 successful detections in a gate of 8 before the system will respond to the contact,

Operator Efficiency (0.) - defines how successful the operator is at responding to a valid contact i.e. what percentage of contacts that meet S_p the operator responds to and injects as a contact in the tactical command system. In the Hunt Class MCMV O_e is approximately 0.7 during Weapon Practice Assessment (wPA) trials.

Operator Delay (O_d) - defines how long it takes for the operator to inject the contact (success on both S_p and O_e) into the tactical command system. In search scenarios where closing speeds between ship and target are small O_d has little significance on calculating the target to ship range (TSR). However, in faster moving scenarios where closing rates are high O_d can become significant.

Radar Range Scale - is the radar scale setting that is used in a realistic scenario and is user defined. If this value is not of particular importance, setting it to a very large figure (e.g. 1000 nm) will in effect remove its influence on the modelled scenario.

AIO inject time **delay** - The Action Information Organisation time delay can be calculated from empirical sources e.g. time measurements during trials or standard reaction times as stated in tactical manuals.

MODES OF OPERATION

TDRSS operates in two modes: In-Depth and Snapshot to support analytical and operational requirements respectively. In Snapshot mode the user will have reduced capability for modifying datafiles and displaying results.

TDRSS uses the radar system transmission characteristics and the target RCS to produce path-1oss figures covering all valid Probability of Detection (PoD) values, The following sections outline the algorithms used in calculating the path-1oss values given the selected mode of operation.

SNAPSHOT

To derive the path-loss values, TDRSS in the Snapshot mode utilises the radar equation 1 *[King 1989]* to calculate the radar free space detection range (R_{fs}) and pat h-loss over the distance of R_{fs}:

$$R' = \frac{P_t G^2 \sigma \lambda^2}{(4\pi)^3 (S/N)_0 N\, k T_0 L\, B_N}$$

Equation 1: Radar Equation

where:

R = radar free-space detection range in km
P_t = peak power in kW
G = antenna gain in dB m^2
σ · target RCS in m^2
λ · radar's transmitting wavelength in MHz
$(S/N)_0$ = single pulse signal to noise ratio required for detection
N = receiver noise figure in MHz
k · **Boltzmann's constant ($1.3807 * 10^{-23}$ JK^{-1})**
TO = **ambient temperature** (290K)
L = **assumed system losses**
$B_N = 1/\iota$ = **noise bandwidth of the i.f filter,** taken to be the inverse of pulse length ι.

The single pulse signal-to-noise ratio $(S/N)_0$ is dependent on the required probability of detection PoD, the probability of false alarm (PFA) and the target fluctuation model (i.e. Swerling case). For the snapshot mode of TDRSS, all targets are fluctuating i.e. Swerling case 1, The probability of false alarms is assumed to be constant at 10^{-8}.

In the Snapshot mode of operation, TDRSS adopts the IREPS algorithm for calculating path-loss.

The equivalent one-way path-loss *[Hattan 1989]* at free space range is calculated using equation 2.

$$Loss = 32.45 + 20 \log(R_{fs} f_{MHz})$$

Equation 2: Path-loss equation

where:

R_{fs} = radar free-space detection range in km
f_{MHz} = radar system frequency in megahertz

IN-DEPTH

The In-Depth mode uses the Engineering Refractive Prediction System (EREPS) algorithms *[Hattan 1989]*. The EREPS algorithm allows the representation of non-fluctuating and slowly fluctuating targets (Swerling case O and 1 respectively),

The EREPS algorithm determines the radar free-space ranges for arbitrary radar cross sections for any probability of detection between 0.1 and 0.9. and for any probability of false alarm between 10^{-2} and 10^{-4}. The corresponding one-way free-space path-loss at the free-space range is also calculated.

The equation used in the calculation of radar free-space detection range is given below:

$$R_{fs} = 58.0 \left(\frac{G_t^{2}\, P_t\, \sigma\, \tau}{f_{MHz}^{2}\, N_f\, (S/N)_{min}\, L} \right)^{1/4}$$

Equation 3: Radar free space equation

where:

- R_{fs} = maximum radar free-space detection range in kilometres
- P_t = transmitted power in kilowatts
- G_t = radar antenna power gain ratio
- σ = target RCS in m^2
- τ = pulse width (or length) in microseconds
- f_{MHz} = radar system frequency in megahertz
- $(S/N)_{min}$ = minimum signal to noise ratio for a specified probability of detection, probability of false alarms, and Swerling case O or 1
- N_f = receiving system noise figure
- L = assumed system losses expressed as a ratio

This process results in a R_{fs} path-loss value against PoD table for given RCS values.

METHOD

With the reference R_{fs} path-loss vs PoD table devised; it is a matter of pattern-matching the path-loss values calculated from the propagation module with those in the reference table to produce a corresponding probability of detection.

This process is repeated for each path-loss value. The final output is a composite PoD vs range table which may be displayed as the graph in Figure 1. This table is a vital data requirement used in the overall identification procedure. In the generation of the PoD against range table, TDRSS assumes that all targets have a constant RCS, are at a constant height and travel on a radial path. It is planned to update this facility to take into account crossing targets (hence varying RCS) and changing heights.

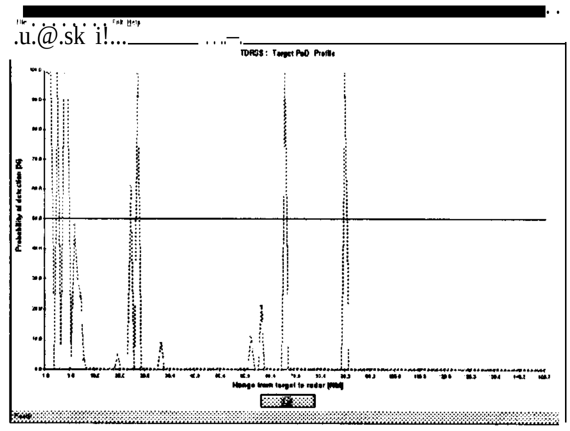

Figure 1: Probability vs Range Graph

TDRSS uses the PoD against range to investigate the performance of radar systems in detecting incoming targets and generate tactically useful information on the performance of a chosen radar system in particular scenarios.

The TDRSS model is based upon a simple model of radar performance: blip-scan theory. This assumes that the outcomes of successive radar scans are independent. It also defines a detection criteria which must be satisfied before a target can be defined as a valid contact *[United States Naval Institute, 1977]*. TDRSS expands on the blip-scan theory by including factors relating to operator efficiency and target inject delays.

An initial expression for indicating whether or not radar target correlation has occurred based on the blip-scan theory can be characterised by equation 4.

$$\left[\left(\sum_{i=1}^{s} f(i) \right) \geq d \right]$$

Equation 4: Radar Target Correlation Expression

where:

- **s = number of stored consecutive scans of the radar antenna**
- **d = number of detections required to correlate a target**

f(i) = function returns 1 if target detection occurred on scan i, O otherwise.

In order to determine if detection has occurred at a given time. the following information is required:

- the range from the target to the radar;
- the target probability of detection at that range:
- whether or not the radar beam is sweeping over the target i.e. if there is a detection opportunity.

Determining the result of a detection opportunity is formulated in equation 5,

$$\left[(f(rand) \leq PoD(rt) \wedge f(illum)\right]$$

Equation 5: **Detection opportunity expression**

where:

f(rand) = a function that returns a randomly generated value in a range O-1
r t = range from the radar to the target
PoD = probability of detection of the target at a given range
f(illum) = a function indicating whether a target is being illuminated or not.

Combining Equation 4 and 5 gives the following simple radar target identification expression:

$$Id = \left[\left(\Sigma_{i=1}^{S}\left[f(rand) \leq PoD(rt)) \wedge f(illum)\right]\right) \geq d\right]$$

Equation 6: Identification Expression

The function f(rand) is required to provide the model with a means of performing Monte Carlo simulation of the detection scenario. This expression is not adequate to represent the entire identification process. It must also take into account the following:

- operator efficiency;
- radar range scale;
- information processing delay;
- tactical identification range.

$$\left[(scale \geq rd) \wedge (f(r) \wedge o_e)\right]$$

Equation 7: Recognition of Target

Target (inject range) = $(r_i - (s_t$ *de@))

Equation 8: Target range **at inject into AIO**

where:

scale = the maximum radius of the radar display scale range
r_d = the range at which the target detection has been fulfilled
f(r) = function returning a random variable in steps of 0.001
o_e = a value representing operator efficiency (between O and 1)
r, = the range at which the target has been identified by the operator
s_t = the speed of the target
delay = time delay between target identification and inject into AIO

The process of calculating the range at which a valid inject occurs (inject range), and the target becomes tactically significant is repeated a number of times in accordance with Monte Carlo modelling methods, TDRS S defaults to 1000 repetitions for scenario modelling, although any user-defined number may be performed

OUTPUT

TDRSS outputs the target range at which it has determined a target inject would taken place. The results may be displayed either graphically (in the form of statistical graphs) or in pre-defined tables of values.

The cumulative frequency graph produced by TDRSS will aid tactical decision makers in their analysis. For instance, there might be a requirement to determine the range at which a particular radar system will detect an incoming missile to a 75% confidence level, this can easily be read off the cumulative frequency graph. Figure 2 shows the cumulative frequency graph produced by TDRSS.

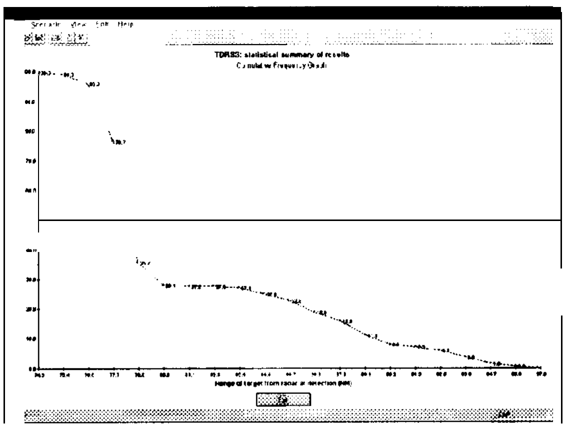

Figure 2: Cumulative Frequency Graph

TDRSS also provides a small statistics module for analysis of the results. values such as the mean detection range. standard deviation, maxima and minima can be determined (Figure 3). The results generated by TDRSS provide the capability for mission planning and/or front-line battle management that requires rapid responses to a constantly changing scenario.

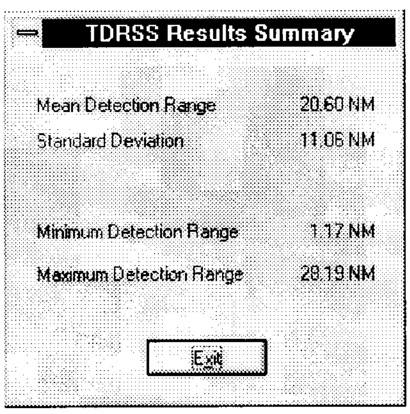

Figure 3: TDRSS Results Summary

The TDRSS concept performs best when considering radar system performance against very fast moving targets of small radar cross section. In these scenarios target speed. radar antenna rotation rate and operator performance become the dominant factors in determining the scenario outcome.

Traditional predictive models have not considered such scenarios in sufficient depth to provide such comprehensive results. From the implementation of TDRSS. the RN can evaluate whether the 50% PoD is the most tactically useful reference to use and consider whether a different PoD may provide a greater confidence limit.

FUTURE DEVELOPMENTS

Future developments include modifying the TDRSS module to handle crossing targets.

Although Blue-Water EEMS is capable of calculating EM wave propagation over terrain, this functionality will not become effective until the integration 'of the Terrain Handling utility in the next stage of EEMS development.

The IT Implementation of EEMS (v2.0) will consist of TERPEM; TDRSS; Terrain handling (THEEMS): High Frequency (HF EEMS) and an Electro-Optical (EO) tactical decision aid.

CONCLUSION

The IT implementation for Blue-Water EEMS (v1 .0) is near completion and following further evaluation will be used operationally in Jan 97.

EEMS (v2.0) is currently in the planning stage. Delivery for operational use is expected end of 1997.

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